

Environmental Influences on Development of Type 2 Diabetes and Obesity: Challenges in Personalizing Prevention and Management

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Abstract

Recent epidemic increases in the U.S. prevalence of obesity and diabetes are a consequence of widespread environmental changes affecting energy balance and its regulation. These environmental changes range from exposure to endocrine disrupting pollutants to shortened sleep duration to physical inactivity to excess caloric intake. Overall, we need a better understanding of the factors affecting individual susceptibility and resistance to adverse exposures and behaviors and of determinants of individual response to treatment. Obesity and diabetes prevention will require responding to two primary behavioral risk factors: excess energy intake and insufficient energy expenditure. Adverse food environments (external, nonphysiological influences on eating behaviors) contribute to excess caloric intake but can be countered through behavioral and economic approaches. Adverse built environments, which can be modified to foster more physical activity, are promising venues for community-level intervention. Techniques to help people to modulate energy intake and increase energy expenditure must address their personal situations: health literacy, psychological factors, and social relationships. Behaviorally oriented translational research can help in developing useful interventions and environmental modifications that are tailored to individual needs.

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Introduction: Environmental Influences on Diabetes and Obesity

Societal changes occurring since 1985 have led to a remarkable increase in the prevalence of obesity among adults and overweight/obesity in children.¹ By 2007, 25.6% of U.S. adults were obese by self-report.² The highest regional prevalence (27%) was in the South, exceeding 30% in three states (Alabama, Mississippi, and Tennessee).² Correspondingly, in 2005–2006, 16.3% of children and adolescents 2–19 years of age were overweight or obese.³ On the heels of this rise in obesity, there has been a

near doubling of the incidence rate for newly diagnosed cases of diabetes among adults, from 4.8 cases/1000 population to 9.1/1000.⁴ Among the states, there is nearly a three-fold range, from a low in Minnesota (5.0/1000) to a high in Puerto Rico (12.8/1000).⁴ Native Americans and Alaska natives are at especially high risk; in adults, the prevalence of obesity is 34% and overall diabetes prevalence is conservatively estimated at 13% (2–3 times the U.S. national average for U.S. whites).⁵ There also is

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Abbreviations: (BMI) body mass index [weight (kg)/height (m²)], (BPA) bisphenol A, (DPP) Diabetes Prevention Program

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great variation among tribes, with the highest diabetes prevalence (>60%) observed in the Arizona Pima Indians.⁶ Demographic estimates project a U.S. national population prevalence of diabetes as high as 12.0% by 2050, a societal burden of huge potential cost.⁷ Type 2 diabetes is rare in youth but is also suspected to be increasing, especially among Native Americans and other ethnic minority groups with a high prevalence of obesity.⁸⁻¹⁰

This article will consider the meaning of “environment” in the context of diabetes and obesity risk. How can a broad concept of environment help us to develop improved approaches for prevention and management? The concept of “personalized medicine” refers to the individual genetic/genomic and psychosocial determinants of risk and of response to treatment or intervention. Individuals are exposed to and interact with multiple environments: the physical environment (chemical exposures and daily light/dark cycles), the “built” environment, and, of course, the food environment. People also exist within a less tangible but no less important psychosocial and socio-economic environment, which includes their internal psychological state, their social interactions, and their capacity to process the information to which they are exposed. Personally and locally tailored solutions will be needed to help people grapple with the specific environments and risk factors to which they are exposed.

Endocrine Disrupters

The natural, physical world first comes to mind with the term “environment.” The concept of environmental exposures connotes pollution of air and water, as well as other passive chemical exposures. Endocrine-disrupting chemicals in the environment first drew public health attention with regard to their possible effects on human fertility and reproductive tissues.¹¹ Endocrine disrupters are chemically diverse and include estrogen receptor agonists (such as diethylstilbestrol, bisphenol A [BPA], and the phytoestrogen, genistein), androgen receptor antagonists (such as phthalates), and aryl hydrocarbon receptor agonists (such as dioxins).¹² The estrogen mimetic, BPA, is used to make polycarbonate plastics for coatings and food containers (including baby bottles). Bisphenol A has been implicated in the development of obesity due to disrupted patterns of hormone regulation and adipocyte differentiation that could affect growth, food intake, adipose tissue distribution and function, and insulin sensitivity.^{12,13} Bisphenol A has long been known to leach from plastics and to have deleterious health effects at low levels in experimental animal models. Of particular concern is the possibility that in utero and

early childhood exposure can lead to lifelong deleterious epigenetic changes that can affect adult health and be passed on to offspring. These concerns have been strengthened by reports based on the ubiquitous presence of BPA in human urine¹⁴ and positive associations of urinary levels with risk of diabetes and cardiovascular disease.¹⁵ Legislative and manufacturing solutions have already been attempted, focusing primarily on eliminating BPA from baby bottles.¹⁶ Research needs, as detailed in an expert panel report, include clarifying biological mechanisms, developing methods for mitigating exposures, characterizing the etiologic relationships of BPA with human health across the lifespan, and developing markers of risk and exposure to better identify genetically and phenotypically susceptible individuals.¹⁷

Circadian Rhythms and Sleep

All living things evolved in synchrony with Earth’s cycles of light and dark, and every cell in the body has molecular clocks that regulate and synchronize myriad physiological functions, including hormone metabolism.¹⁸ The daily experience of sleep is critical to “setting” these clocks. Therefore, the impact of inadequate sleep time is of public health concern. In 2009, 20% of Americans reported sleeping <6 h/night (versus 13% in 2001), and 28% reported sleeping >8 h/night (versus 38% in 2001).¹⁹ Sleep deprivation is known to have behavioral consequences such as decreased alertness, accidents, and emotional disturbances.²⁰ Short sleep duration is associated with overweight and obesity and with risk of developing diabetes as well.^{21,22} Obstructive sleep apnea and other forms of sleep-disordered breathing are well-known comorbidities of overweight, obesity, and type 2 diabetes, requiring treatment to minimize cardiovascular risk.²³ However, recent hypothesis-testing research in humans and animals indicates that sleep disturbances also play a causal role in generating or exacerbating problems of energy balance and insulin function.²²⁻²⁵ Misalignment of sleep/wake cycles and eating behavior (for example, eating late at night) is thought to distort the normal synchronization of metabolic gene transcription.²⁶ Conversely, eating behavior and food ingestion appear capable of entraining hypothalamic oscillators affecting multiple physiologic systems.²⁶ These findings are intriguing given the importance of timing and composition of meals in controlling blood sugar in type 2 diabetes. Also, work in animal models suggests that metabolomic profiling may have the potential to identify internal clocks, suggesting that therapy could be personalized to the individual’s body clock (“chronotherapy”) once this technology becomes available for humans.²⁷ Thus, with

further basic and applied research,²⁸ personal and public health-level sleep interventions might have the potential to complement other management approaches to weight and diabetes.

Environmental Influences on Food Intake and Physical Activity

The obesity epidemic is an unintended biological consequence of powerful economic forces, which have led to a widespread imbalance between energy expenditure and energy intake. Labor and time have a relatively high value, promoting the use of labor-saving and time-saving technologies in the home and workplace. Physical activity has declined steadily since 1960, reflecting declining work-related activity, increasing sedentary activity (e.g., time spent using computers or watching television), increased automobile travel time from home to work, and increases in automobile use versus walking or public transit.²⁹ Also, surprisingly large decrements in at-home energy expenditure (>100 kcal/d) can be attributed to transition to labor-efficient technologies.³⁰ Use of food prepared outside the home has risen such that it now accounts for approximately half of food expenditures.³¹ These commercially prepared foods tend to have increasingly large portion sizes, as food costs are relatively low compared to labor costs.³²

Environmental drivers of overeating include not only the presentation of large portions, but also the ubiquitous availability of food, social acceptance of frequent eating, little or confusing information about the energy content of foods, and susceptibility to food marketing tools such as packaging, image identity, and indirect product enhancements.^{33,34} Perception of such external influences can be quite inaccurate. Eating larger quantities in the presence of other eaters may be attributed to physiologic sensations (such as hunger) but actually is due to social mirroring³⁵ or other complex decision-making phenomena.³⁶ These external influences on eating behavior need to be understood in order to develop effective interventions. Conversely, ingenious applications of marketing research also may suggest useful interventions, such as switching to smaller plate sizes to encourage lower calorie intake.^{33,37}

The “built environment” is emerging as an important dimension of environmental risk for higher rates of obesity.²⁹ “Built environment” is a relatively new term that refers to the patterns of human behavior within the physical world, encompassing urban design (arrangement, appearance, and function of physical elements and public spaces in cities), land use (location and density

of residential, commercial, and recreational structures and activities), and transportation systems (usage patterns and physical infrastructure).³⁸ Research on the built environment uses methodology drawn from the disciplines of urban planning and architecture. Buildings are evaluated for the presence of well-lit, safe staircases, recreational space, office layouts that encourage walking around, and recreational facilities. Schools are assessed for classroom space for movement versus sitting, access via walking, the presence of safe playgrounds, and proximity to fast-food outlets. Neighborhoods and communities are studied using global positioning technologies for land-use mix, distribution of fast-food outlets, street connectivity, presence of green/open space, access to public transportation, density of public transit stations, street crime rate, availability of standard grocery stores, and presence of recreational facilities. Although causality has not been proven between weight gain and features of built environment, recent research is confirming dose-response associations. For example, in Portland, Oregon, a 10% increase in land-use mix has been associated with a 25% reduction in the prevalence of overweight/obesity, and a one standard deviation increase in the density of fast-food outlets has been associated with a 7% increase in overweight/obesity.³⁹

Environmental inequity, i.e., living in an especially adverse physical and social environment, is thought to contribute to the higher risk of developing obesity and diabetes and of suffering complications of disease that is experienced by members of minority and economically disadvantaged demographic groups.⁴⁰ Individuals living in low-income neighborhoods or who are at social disadvantage frequently live with many of the environmental and social issues discussed in this essay. These include exposure to circadian stress (shift work, double shifts) and living in an unhealthy built environment with poor access to physical activity venues (few recreational facilities, safety issues), healthful food supply, and health providers. Literacy, numeracy (numerical literacy), and health literacy are typically weak in these communities, and people may have a poor sense of autonomy and control over their environments and low self-efficacy for behavior change.

Information Environment: Nutrition and Diabetes Aspects

Guidance for lifestyle modification, including dietary change, presumes that the individual can absorb the concepts of what makes a better diet and then will make better decisions about what to eat. Nutrition information is complex, however, and includes choice of foods,

portion sizes, nutrient content information for multiple nutrients, and relative rankings of nutrient content among foods. We ask patients to integrate multiple simultaneous variables and to choose foods that meet guidelines for calories (weight); for sodium, cholesterol, saturated fat, and trans fat (blood pressure and plasma lipids); and for type, amount, and timing of carbohydrate (diabetes, especially when using insulin). This is a daunting task. Food labels make this information readily available, but reading, understanding, and utilizing Nutrition Facts Panel data requires literacy and numeracy skills at approximately the 6–9th grade level. In fact, many adult Americans do not have these skills; the U.S. Department of Education's 2003 National Assessment of Adult Literacy found that 35% of surveyed adults had "basic" or "below basic" skills for document literacy (necessary to understand text) and that 55% had basic or below basic skills for quantitative literacy (necessary to do simple arithmetical calculations).⁴¹ These common problems with literacy, and especially with numeracy, have been observed in primary care patient populations.⁴² In fact, it has been suggested that the ability to understand and use food label information be used as a quick test of literacy skills for following primary care information.⁴³ With aging, the difficulties are compounded. There often is an erosion of skills (such as short-term memory and working memory) needed for cognitive processing of food label information.⁴⁴

Individuals with obesity and/or diabetes are more likely to be older and to have lower educational attainment and lower English proficiency. It is worrisome that many educational materials provided by the American Diabetes Association and American Heart Association materials are unsuitable for low-literacy populations.⁴⁵ The cognitive processing demand of even the simplest diabetes education information is intimidating, and we must develop new ways to enhance competency and self-confidence of patients. In addition, the elderly and those with diabetes often suffer from impaired vision, which will further compound their difficulties with printed materials. An effective information environment for diabetes and obesity prevention and treatment for adults and children will require individualized assessment, perhaps based on diagnostic tests, and a suitable educational approach that provides print and nonprint educational materials matched to the patient's skill level and learning style.⁴⁶

The Need for Translational Research

A useful model for describing the stages of prevention and better management of obesity and diabetes can be drawn from the world of cardiovascular disease

prevention.⁴⁷ *Primordial prevention* seeks to prevent risk factors from developing especially in children, youth, and young adults (e.g., maintain healthy weight and prevent development of overweight and obesity). *Primary prevention* seeks to prevent risk factors from causing disease (e.g., reduce likelihood of transitioning from prediabetes to diabetes). *Secondary prevention* seeks to prevent adverse disease outcomes (e.g., optimize diabetes management to prevent complications).

Understanding the capacity of comprehensive environmental change to reduce individual and population risk of obesity and diabetes will require what is now being termed "type 2 translational research", the "bedside-to-curbside" complement of "bench-to-bedside" translational research that brings basic science findings to the clinic.⁴⁸ Well-designed randomized trials and studies taking advantage of natural experiments are needed to estimate the effects of multiple environmental changes. Research and practical approaches for prevention and treatment must be directed at different groups within society depending on their needs. These needs will vary with age (children, adolescents, retirees) and risk level (primordial and primary prevention in the general population, secondary prevention in high risk populations). Studies must be designed to compare effectiveness of interventions in a variety of settings (health care environments, communities, schools) with public and private partners. Identifying and then implementing effective techniques at the individual and community levels will require the tools of behaviorally based "implementation science" so that basic science and clinical knowledge can be translated into public health programs and thence into improved public health.

Interventions: Potential for Change

Eating and physical activity behaviors are known to have shifted in response to powerful social and economic forces, with deleterious effects on body weight and diabetes. How are individuals to push back or grapple with these forces, either individually or collectively? It is useful to have a framework for understanding what is involved for individuals to change their eating, activity, and other habits.

There is ample literature on the factors involved with health behavior change and disease management behavior, especially in terms of achieving adherence to treatment recommendations. Numerous theories and models have been developed to design research, to account for observational data, to predict what people will do, and

to develop effective therapeutic, counseling, and other practical approaches.^{49,50} Many models focus on personal determinants of individual behavior (classic learning theories, health belief model, transtheoretical model, relapse prevention model) while others more fully incorporate the role of interpersonal relationships (social cognitive theory, planned behavior theory) and social supports.⁵⁰

There also is growing interest in ecological models of behavior change^{50,51} that accommodate the social environment in which the person lives, such as institutional factors, public policy, and interpersonal and group relationships. The potential of these models was reinforced by a social network analysis based on the Framingham Heart Study cohort, which found that the probability of becoming obese was higher among individuals who associated with other obese people.⁵² A parallel study in adolescents also identified peer influences on body mass index (BMI).⁵³ A vigorous debate has ensued about whether this type of modeling is a valid way of inferring shared behaviors or standards of reference (i.e., is a heavy body weight acceptable?) or whether it actually is assessing contextual influences (i.e., access to shared environment, such as fast-food restaurants or walkable communities).^{54,55} Either way, these findings imply that community-level interventions will be critical for achieving progress in reducing the prevalence of obesity.

The 2008 Physical Activity Guidelines for Americans point out that moderate levels of activity, however achieved, are associated with a 30–40% lower risk of developing type 2 diabetes and metabolic syndrome.⁵⁶ Indeed, lifestyle intervention programs focusing on individual behavior modification have been proven effective in improving cardiovascular and diabetes risk factors in adults. For example, the Diabetes Prevention Program (DPP) found that modest weight loss (7%) and increased physical activity (walking 150 min/week) reduced the 3 y incidence of diabetes in individuals with impaired glucose tolerance (prediabetes) by nearly 60%.⁵⁷ Similarly, the PREMIER trial showed that improved diet and exercise habits, reinforced by counseling for goal-setting, self-monitoring, and problem-solving, were effective in promoting weight loss and lowering blood pressure in individuals with prehypertension or stage 1 hypertension.⁵⁸ The DPP program has been successfully implemented in other settings for adults,⁵⁹ but for youth at high risk of prediabetes, more research is needed to determine effective interventions.^{60,61} Nevertheless, these randomized counseling-oriented interventions are very

labor-intensive and would be hard to implement under many situations, especially for children. School-based or multicomponent designs (e.g., diet, exercise, reduced screen time) that include a focus on parental involvement^{62–65} can be effective approaches to obesity prevention and treatment in children and adolescents. Community-level interventions for helping youth and families maintain a healthy weight (such as the We Can! Program) also hold great promise.^{51,66} Diabetes self-management training, including approaches that engage family, can be effective in improving glycemic control,^{67,68} but research that better addresses environmental and community setting issues is needed.^{69,70}

Conclusion: Moving to “Diabetesville”

Imagine this family: two kids (inactive elementary and middle school students, overweight by 10–20 lb), their mom (BMI = 35, with a history of gestational diabetes), and their dad (BMI = 32, with metabolic syndrome and a family history of type 2 diabetes). This hypothetical family has multiple behavioral risk factors and possibly a social network of similarly overweight friends, neighbors, and relatives. Their propensity to obesity and diabetes likely has a genetic component that would not have manifested itself 30 years ago when the food environment and daily physical activity levels were more favorable.

Now imagine that, one evening, the parents come home from work, roust the children from watching TV, and, as they eat their fast-food dinner, announce, “Kids, we’re moving to Diabetesville. It’s a community not far from here where everything is set up to help us improve our habits. We’re going to buy a house there, you’re going to go to school there, and we’ll all do better.”

What would Diabetesville be like? Of course, there must be adequate attention to ethical and legal concerns, such as protection of free speech, free trade, and the opportunity to exercise free will (i.e., avoiding a “nutrition police” atmosphere). However, many aspects of the food environment, the built environment, and the social environment could be favorably altered:

- grocery stores (accessible locations, more nutritious food items, single-serving or limited-calorie packaging, nutrition information, checkout register comparisons against nutrition guidelines, menu planning services)
- restaurants (smaller servings, more nutritious recipes, nutrition information for menu items)

- consumer goods (smart clothing to monitor metabolic status, such as shirts to detect hemoglobin A1c levels, shoes to monitor skin oxygenation in diabetic feet, wrist devices to monitor physical activity and outdoor recreation; furniture to detect inactivity)
- neighborhood design (presence of sidewalks, access to public transportation, safe environment, parks, presence of recreational facilities, stair-friendly public buildings)
- public schools (cafeteria and vending machine offerings, classroom food policies, protected physical education time, sleep-friendly start times, nutrition/physical activity curriculum modules, movement-friendly building layout, fitness/health/BMI reports)
- satisfactory access to health services and health education
- community-level social marketing to encourage healthful behaviors

Natural economic pressures toward convenience and time saving are at the heart of the obesity epidemic. Conversely, interventions perceived as personally inconvenient, difficult, or costly will not succeed. Weight loss and physical activity interventions must address genuine time and economic costs, such as taking time to exercise and to prepare more nutritious meals, and the price of more nutritious foodstuffs or having access to recreational facilities.

In theory, more movement and a higher level of everyday or leisure-time physical activity might lead to improved strength, balance, aerobic capacity, and improved insulin sensitivity. Lower caloric intake, in conjunction with higher activity level, might lead to modest but medically useful weight loss. A better balanced diet, higher in nutrient density, lower in salt, and possibly with a lower glycemic load, might lead to improved glycemic control and better micronutrient status and blood pressure control. A community atmosphere that facilitates adherence to preventive and therapeutic recommendations and provides the means of achieving them, might promote confidence and self-efficacy.⁷¹

Would moving to Diabetesville really “work” for our hypothetical high-risk family? The answer is we don’t really know. Too little is known about the potential impact of environmental change and how best to evaluate it.⁷² We also don’t know enough about genetic, genomic, and psychological propensities that mediate the individual’s

risk from environmental factors, nor how to tailor dietary and other interventions for individual benefit.⁷³ However, in the meantime, given that two-thirds of the population is now affected by diabetes or obesity or their risk factors, there likely are few U.S. families who would not benefit from living in Diabetesville.

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